Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

Congress, embodying changes in the original concession of the Bolivia Railway Co. The changes were made at the request of the American syndicate building the road. It is a step toward the consolidation of the interests of these two roads and will undoubtedly result in the unification of the railway systems of Bolivia. By the terms of the agreement now embodied in the law, the British company (The Antofagasta and Bolivia Railway Co.) guarantees the interest on the new line of the American company (The Bolivia Railway Co.) just completed between Viachi and Oruro, and makes a payment to the American syndicate for a majority of the new line's stock. The original terms of the American syndicate's concession were still further modified with reference to the remaining lines now projected or actually under construction. It is the general purpose of these changes to make the new lines serve as feeders instead of competing lines to the Antofagasta Railway.*

---

* *Bull.* of the Intern. Bureau of Am. Republics. Jan., 1909, p. 111 *et seq.*

(*To be continued.*)

THE EXPLORATION OF THE UPPER AIR*

BY

ANDREW WATT, M.A., F.R.S.E.,
Secretary to the Scottish Meteorological Society.

Much light has been thrown upon the movements and conditions of the higher atmosphere by observations made upon mountain summits, such as Ben Nevis, and we hope that some day there will be again a high-level station somewhere in the British Isles—supported by Government. It is indeed true that observations made upon mountain peaks and those obtained from some point in the free atmosphere represent different sets of conditions, and that the presence of the mountain itself affects the records. For example, it is probably true, as a rule, that the air on a mountain summit is distinctly colder than that at a point at an equal height in the free air close by. But we are not aware that any advocate of high-level stations has claimed that mountain observations should be regarded as identical with those made in the free atmosphere; and the fact remains that, as a rule, of all observations made at a considerable height, only those obtained from some point on the earth's surface could be reported to a central office in time to be charted on the current Daily Weather Map, and examined in connection with simultaneous low-level readings within an hour or two of the time of observation. On the other hand upward soundings in the free atmosphere are restricted neither by latitude nor by longitude, and many observations have been obtained from points at more than twice the height of Everest above the level of the sea. Modern meteorology has become a science dealing with space of three dimensions.

---

* This excellent summary of the nature and results of researches in the free atmosphere, made during the past few years, is reprinted from the annual *Journal* of the Scottish Meteorological Society, Edinburgh, Vol. 15, 3d Series, No. 26. The footnotes give references to publications in which may be found the original accounts of these researches. The *Bulletin* is indebted to Mr. Watt and the Scottish Meteorological Society for the opportunity to reprint this paper dealing with, perhaps, the most brilliant chapter in the history of meteorology.

The exploration of the free atmosphere has been conducted by means of—(1) kites; (2) manned balloons; (3) "ballons sondes," or balloons carrying self-registering instruments only. Pilot-balloons carrying no instruments, and liberated merely to show the drift of the upper-air currets, are also used. It will be convenient if we give brief historical notes on the development of these various agencies.*

First of all, as regards kites. It is commonly supposed that Benjamin Franklin, in his famous experiments for collecting atmospheric electricity, made at Philadelphia in 1752, was the first to use the kite for scientific purposes. But that is not the case, for, three years earlier, Dr. Alexander Wilson, Professor of Practical Astronomy in the University of Glasgow, had used kites to raise thermometers in the air in an attempt to investigate the temperature at different heights.† Apparently nothing further was done until towards the middle of the nineteenth century, when Espy, in America, did some useful work. Later, in the eighties, Archibald, in England, experimented extensively on the best form of kite, and was the first to use pianoforte steel wire, which was at once stronger, smaller, lighter, and cheaper than that of copper and iron, formerly used. But it was not until Mr. A. L. Rotch took up the matter at his private observatory on Blue Hill, near Boston, in Massachusetts, that a systematic investigation of the upper air by means of kites was anywhere attempted. That now famous observatory was founded by Mr. Rotch in 1885 on ground purchased by him, and for more than twenty years reports of the various investigations have been published by Harvard University. Kites were first employed in 1894, and since that time a continuous survey of the atmosphere up to a height of about two miles has been conducted, yielding results of the greatest value. The kites employed at Blue Hill are of a modified Hargrave or box pattern, and the Blue Hill type has been very generally adopted elsewhere.* As a rule, two or more kites linked together are used, and, as far as we are aware, the highest observations ever secured by means of kites were made by a team of six from Lindenberg, near Berlin, in November, 1905, when an elevation of about 21,000 feet was reached.†

---

* Anyone dealing with the history of the subject must be greatly indebted to A. L. Rotch's "Sounding the Ocean of Air." (London: Society for promoting Christian Knowledge.)

† *Trans.* Roy. Soc. Edin., vol. x. part ii. pp. 284–286.

In 1901 the exploration of the atmosphere by means of kites received a great impetus. The method had obviously its limitations; there might be too much wind or too little, and an extensive kite campaign organized by the Weather Bureau of the United States of America was not a complete success owing to the lightness of the winds experienced.‡ It was found that at a land station kites could be raised only in a wind of twelve miles per hour, and that in calm anti-cyclonic weather they were of but little use. Mr. Rotch now suggested that from a steamer, where even in calm weather there was always an artificial wind equal to at least the speed of the steamer, kites could be flown in all weathers, since the lifting powers of strong winds could be modified by steaming against or at an angle to them; and Mr. Rotch, after some preliminary experiments, himself demonstrated the value of his suggestion by making some very successful kite flights in crossing the Atlantic in the steamship *Commonwealth* at the end of August, 1901.§

This enterprise may be said to have been the inspiration of the recent energetic work in England in upper-air meteorology, for Mr. Rotch's account of his experiments to the British Association at Glasgow (September, 1901) made such a deep impression that a grant was voted to initiate experiments by means of kites, and a joint committee of the Association and of the Royal Meteorological Society was appointed to administer the grant.‖ This committee, with Dr. Shaw as chairman, and Mr. W. H. Dines as secretary, has been reappointed from year to year, though latterly without a grant. Aerial research in the British Isles is greatly indebted to the vigorous work of the Royal Meteorological Society, whilst during the last four years the Meteorological Committee have assigned a considerable sum for the work, with Mr. Dines as their official investigator. The first soundings of the free upper air in this country were made by Mr. Dines from a small steamboat at Crinan in the summer of 1902, that place recommending itself by its comparative seclusion and its proximity to the Atlantic and to Ben Nevis, and the Crinan ascents have been continued in succeeding summers. It is probably a sign of the times that one of the younger universities has been the first to associate itself with meteorological research in England, for the Physical Laboratory of the University of Manchester has established at the Howard Estate, on Glossop Moor, a well-equipped station for the investigation of the upper air. Since the Meteorological Office has associated itself with the work, results of ascents from various stations are published with remarkable promptness in the *Weekly Weather Report,* so that within a few days of the close of each week there is available a very full account of the low-level meteorological conditions of the week, and also a considerable amount of information as to the conditions at higher levels. At present there are, as a rule, reports from the Glossop Moor station; from Mr. Dines at Pyrton Hill, in Oxfordshire; and from two enthusiastic private observers—Mr. C. J. P. Cave, of Ditcham Park, and Mr. S. H. R. Salmon, of Brighton.*

---

* For accounts of founding of Blue Hill Observatory, introduction of kites, description of apparatus and methods, and results, see *Annals* of the Astronomical Observatory of Harvard College, especially vols. xx. part i., xlii. part i., and xlviii. part i.

† *Ergebnisse der Arbeiten des Königlich Preussischen Aeronautischen Observatoriums* (1905), Band i. p. 63, Berlin, 1906.

‡ U.S.A. Weather Bureau, Bulletin F.

§ *Nature*, vol. lxv. pp. 4, 545.

‖ *British Association Reports*, 1901–1908,

We pass now to the use of balloons in aerial meteorology. The effective history of ballooning begins with the work of the Montgolfier brothers in France towards the end of the eighteenth century. In 1783, an ascent was made in a "Montgolfière," or heated-air balloon; in the same year the physicist Charles reached an elevation of 9,000 feet above Paris by means of a balloon filled with hydrogen gas; and two years later the Channel was crossed from the English side by a Frenchman and an Englishman in company. Very early the balloon was recognized as of great value for scientific research, and in the early years of last century some well-known names in French science were associated with scientific ballooning. Thus, in 1804, Gay-Lussac reached a height of 23,000 feet, making magnetic and temperature observations. In England, in the fifties, John

---

* For accounts by Mr. Dines of his methods and instruments, see the *Quarterly Journal* of the Royal Meteorological Society, vol. xxix. (1903) p. 65, and vol. xxxi. p. 217; and for various reports on upper-air work, that *Journal*, vols. xxviii. 1, xxx. 155, xxxii. 15 and 29, xxxiv. 15, xxxv. 15 and 37. See also the *Reports of the British Association*, 1902 *et seq.*, and the *Annual Reports of the Meteorological Committee*, especially the Third Report (1908), pp. 43-49.

Welsh, of Kew Observatory, made some important ascents; and then we come to the splendid work of James Glaisher, who, along with Coxwell, the aeronaut, made about thirty ascents between 1862 and 1866, which are described in great detail in the Reports of the British Association. A height of 23,000 feet was thrice exceeded, and on one memorable occasion, from Wolverhampton, on 5th September, 1862, a height of more than 29,000 feet was reached, both Glaisher and Coxwell losing consciousness at that great elevation. Various considerations, such as a comparison of the rate of ascent when he lost consciousness, and the rate of descent when he recovered consciousness, thirteen minutes later, and the fact that "a very delicate minimum thermometer read minus 11°.9 (F.), led Glaisher to the conclusion that a height of 36,000 or 37,000 feet, or fully seven miles, had been reached. This, however, seems doubtful; but, in any case, Glaisher's great feat has been equalled or excelled only in Germany.*

It may be said that aerial research by means of manned balloons in England since Glaisher's ascents of more than forty years ago has been merely spasmodic, and, though other countries have had some small share in research by this means, in Germany alone has this method of work been vigorously pursued. The use of manned balloons obviously involves great expense, and Germany has now in the Imperial Aeronautical Observatory at Lindenberg, near Berlin, of which Dr. Assmann is the distinguished director, by far the most elaborate place of the kind in the world. The German School of Scientific Aeronautics has given great attention to the best exposure of instruments, and the "aspiration psychrometer" of Dr. Assmann has solved a serious difficulty. Thus the temperature readings obtained at great heights by Glaisher were higher than one would *à priori* have expected, and it is now recognized that his thermometers were probably not sufficiently protected from the direct rays of the sun, and that in any case the car of the balloon in which the instruments hung became in its rapid ascent practically a well of relatively warm air which had not time to acquire the true temperature of the various strata through which it passed. These difficulties are entirely overcome by using a properly exposed Assmann psychrometer, in which a fan driven by clockwork ensures a proper circulation of air round the bulbs of the thermometers.

Some great heights have been reached on the German balloon ascents, and that of 31st July, 1901, from Berlin, on which Süring and Berson reached a height of 10,800 metres, or about 6¾ miles, probably represents the extreme altitude attainable by human beings even with the help of artificial means of respiration. On this remarkable voyage the balloon was in the air for seven and a half hours, and came to earth nearly ninety miles from Berlin. Both observers fainted before the highest point was reached, which was determined from a barograph trace, and made their last temperature observation at a height of 10,225 metres, or about 33,500 feet, that is at a point more than 4,000 feet above that at which Glaisher and Coxwell lost consciousness. The temperature at this point was —39°·7 C. (—39°·5 F.), and already at a much lower level the aeronauts found it "empfindlich kalt."

---

* *British Association Reports*, 1862–1866.

The German upper-air work has been of the most thorough description and affords perhaps the only available material for a thorough study of day-to-day temperature changes in the free upper air.*

Whilst Germany may be said to have perfected the use of the manned balloon, and America, or perhaps rather an American, the use of the kite, to M. Teisserenc de Bort, of Trappes, near Paris, falls the credit of having perfected the use of the "ballon sonde," by which the free atmosphere has been explored to an amazing height. It is true that already, in 1892, MM. Hermite and Besançon had sent up to considerable heights balloons made of gold-beater's skin and carrying simple instruments,† but it remained for M. de Bort to fully develop this method, and in 1898 he made some important discoveries by means of large paper balloons covered by a net. Meanwhile Dr. Assmann in Berlin was experimenting with small rubber balloons such as are now universally employed. These are inflated with hydrogen gas only sufficiently to give them an initial upward velocity, and as pressure goes on diminishing with increase of height the gas expands till a point is reached when the balloon bursts, gradually falling to the ground under the protection of a parachute. Though these balloons often travel great distances, the instruments are recovered in a surprising number of cases, and some remarkable elevations have been reached, occasionally more than sixteen miles. M. de Bort's methods have been followed in many countries, and by means of "ballons sondes" the ocean of air has been sounded to great heights at many places from St. Petersburg in the east to St. Louis in the west, and from the Arctic Circle to the Equator.

---

* See "The temperature of the Air above Berlin from 1st October, 1902, until 31st December, 1903, as shown by the Daily Ascents executed by the Aeronautical Observatory of the Royal Meteorological Institute of Prussia." By Professor Dr. Richard Assmann (Berlin), 1904.

Ergebnisse der Arbeiten am Aeronautischen Observatorium. (4 vols. Berlin, 1902–1905).

Ergebnisse der Arbeiten des Königlich Preussischen Aeronautischen Observatoriums bei Lindenberg. (3 vols., Berlin, 1906–1908).

† *Comptes Rendus* Paris [C.R.], vol. cxv. p. 862.

It remains to add that observations of the direction of cirrus clouds have told us a great deal about the movements of the upper air at great heights, and that much useful work has been done by means of pilot balloons.

We have now indicated the various methods by which the exploration of the upper air has been carried on, and may now briefly describe some of the results, dealing chiefly (1) with researches made on the general circulation of the atmosphere, and (2) with investigations of the temperature conditions of the atmosphere at great heights.

When Rotch described to the British Association in 1901 his own successful experiments on the use of kites at sea, he suggested the trade-wind region of the North Atlantic as a promising field for research. You have there the more or less permanent North-East trade, flowing down to the thermal equator where there is a great uprush of heated air, and the problem offered is as to how exactly this air is transferred again to higher latitudes. However, before Rotch himself had an opportunity of exploring the region, Professor Hergesell of Strassburg had secured the co-operation of the Prince of Monaco, and in the summer of 1904 made a cruise of investigation in the *Princesse Alice.* The field covered was the part of the North Atlantic bounded by Spain, the Azores, and the Canaries, and much important information was obtained as to the variation of temperature and humidity with height, etc. One result, however, was of a most unexpected nature. It had long been held that above the North-East trades there flowed the "anti-trade," or return current, from the South-West; and the fact that the prevailing wind on the Peak of Teneriffe, some 12,000 feet high, was from that point confirmed this opinion. Hergesell, however, though his upward soundings on several occasions reached a greater height than 12,000 feet, found no indication of the upper "anti-trade," and concluded that the South-Westerly current observed on the Peak of Teneriffe was due to local influences.*

Hergesell's conclusion was so unexpected that it seemed to Rotch and De Bort an urgent matter that further investigations should be conducted, and, in the following summer (1905), they organized an expedition in the steam yacht *Otaria,*—Mr. Clayton of the Blue Hill Observatory and M. Maurice of Trappes acting as meteorologists. A leisurely voyage was made from the Mediterranean by way of Madeira, the Canaries, and the Cape Verde Islands, as far as latitude 10° N., returning by way of the Azores. Many kite flights were made up to a height of more than a mile, and the wind direction at great heights was observed by means of pilot balloons whose trajectories could be followed up to a height of six or seven miles.† The general result of the expedition may be summed up as follows: The existence of the South-West anti-trade, which theory demanded and the winds on the Peak of Teneriffe indicated, was absolutely confirmed. It was found, however, that the variation of wind direction with height was not altogether simple, and that there was not an immediate transition from a North-Easterly to a South-Westerly direction. The North-East trade was found to be of varying thickness; above that was a layer of North-Westerly winds; and above that the return current up to a height of at least six or seven miles, with a direction varying from South-East to South-West. It was found that the velocity of the trades decreased rapidly with height. Further voyages were made by the *Otaria* in 1906 and 1907 into mid-Atlantic and as far South as Ascension.‡

---

* *C.R.*, cxl., 331.

We may here conveniently point out that earlier theories of the general circulation of the atmosphere, which conceived that part at least of the upper return current from equatorial regions extend to the pole, have been disproved by systematic observations of the direction of the high cirrus clouds in higher latitudes. For it has been shown that in the temperate zone in both hemispheres there is a general motion of the upper air from West to East; indeed, this drift towards the East has been found at least as far North as the Arctic Circle. And to the South of the Equator we have the South-Easterly trades underlying the North-Westerly anti-trades, as has been fully proved by observations of the direction of the upper clouds over Mauritius. Above the region of equatorial calms there flows a steady upper current from the East, as was demonstrated in the most striking manner after the eruption of Mount Krakatoa in August, 1883, for "the optical phenomena caused by the volcanic dust which was carried up into the uppermost layers of the atmosphere travelled round the world from East to West in about twelve or thirteen days, from which it follows that these uppermost currents are endowed with a velocity from the East of eighty-three miles per hour. This velocity is very nearly the same as the mean velocity of the upper clouds at Washington, and is therefore not at all inconceivable."*

---

* *Nature*, vol. lxxii. 244, lxxiii. 54.

† *Nature*, vol. lxxx. 219.

But we cannot leave this part of our subject without referring to an aerological expedition sent out to tropical East Africa in the summer of 1908 by the Royal Prussian Aeronautical Observatory at Lindenberg, though only a sketch of the work done is as yet available. The enterprise, official and private, that despatched such an expedition into the heart of a tropical continent must command the highest admiration. Professor Berson was the leader, and the greater part of the work was conducted from the shores and waters of Lake Victoria Nyanza. A full report of the various researches will be looked forward to with the greatest interest, and it is certainly a very surprising fact that whilst the regular Easterly upper current of the equatorial regions was found, there was on several occasions "an uppermost current of air flowing from due West."†

Passing now to the chief results of studies of temperature conditions in the free atmosphere, we may at once discuss the remarkable discovery by M. de Bort of the so-called "isothermal layer." It was known that temperature inversions occurred, in certain circumstances, on the surface of the earth. Especially is this the case during anti-cyclonic weather in winter, and as an extreme example we may instance a striking departure from the normal relationship between the summit and the base of Ben Nevis that occurred during the great frost of January and February, 1895. The average difference of temperature between Ben Nevis and Fort William ranged from 16°·8 F. in April to 14°·4 in December, the mean for the whole year being 15°·4, whilst at 9 A. M. on 19th February, 1895, the summit was no less than 17°·6 *warmer* than the base. (B.N.O., 33°·6, F. W. 16°·0.)‡

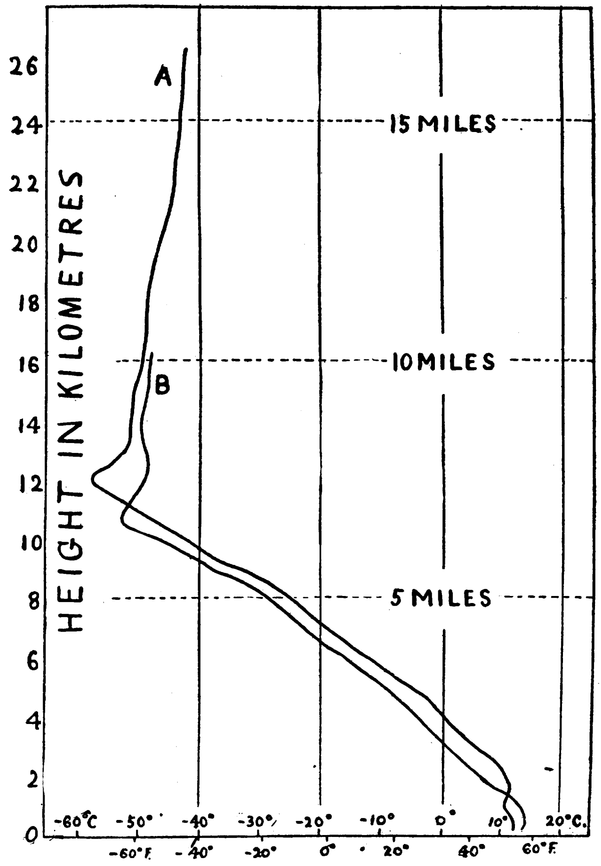
When we pass from the surface of the earth to the free atmosphere we find that there also inversions are met with at moderate and varying heights up to a level of some two miles or more, that is throughout the region in which nearly all clouds except the cirrus are formed. Above this comes a much thicker layer, in which temperature decreases with remarkable regularity, and the ascents of kites and manned balloons had given no indication that this decrease did not go on indefinitely. M. de Bort, however, had not been long at work at Trappes with his "ballons sondes" when he was able to make the announcement that after a certain height, varying from five to nine miles, the fall of temperature ceases and is very often actually reversed. This uppermost region he proposed to call the "zone isotherme," and probably the title "isothermal layer" generally adopted in England has come to stay. It is not, however, altogether satisfactory, as the region indicated is seldom more than approximately isothermal. Moreover it is inappropriate to describe as a layer a region of which the uppermost limit has not yet been reached.*

---

* See Dr. Hildebrandsson's Report to the Permanent International Meteorological Committee on "The International Observations of Clouds," translated in *Quarterly Journal*, Royal Met. Soc., vol. xxx, pp. 317-343.

† *Nature*, vol. lxxx. p. 171.

‡ See a communication by the writer in *Nature*, vol, lxxi. 583.



TEMPERATURES OBTAINED ON "BALLONS SONDES" ASCENTS.

The phenomenon of the "isothermal layer" is well shown in the temperature records obtained on two characteristic "ballon sonde" ascents which are charted in the accompanying diagram. The

---

* *C.R.*, cxxxiv. 987, cxxxviii. 42, cxlv. 149.

Belgians have been very successful in reaching great elevations, and the curve marked A refers to an ascent made from Uccle, near Brussels, on 25th July, 1907, when a height of fully twenty-six kilometres, or more than sixteen miles, was attained. Curve B refers to an ascent made from Trappes two days earlier. It will be observed that in both cases an inversion of temperature occurred near the ground, followed by a long gradual decrease of temperature with a sudden change of gradient at a great height. In A the lowest temperature recorded occurred before the balloon had reached more than half its extreme elevation, and at a height of fifteen miles the temperature was as much as 14° C. (25° F.) higher than at seven and a half miles.

As a further illustration of the phenomenon of the "isothermal layer" we give below actual numerical results obtained on another high ascent from Uccle on 5th November, 1908.* Two rubber balloons in tandem were employed, as is very commonly done, and these remained in the air for nearly two hours, and were recovered at a place about fifty miles to the SSE. The greatest height reached was 29,040 metres, or about eighteen miles, and the lowest temperature, —67°·8 C. (—9°·0 F.), was experienced at 12,950 metres, or about eight miles, that is before the balloon had reached more than half its extreme elevation, as was also the case on the ascent referred to in curve A of our diagram.

HEIGHT.		TEMPERATURE.		HEIGHT.		TEMPERATURE.	
Metres.	Miles. (Approximately.)	C°.	F°.	Metres.	Miles. (Approximately.)	C°.	F°.
100	....	4.4	39.9	12,000	7.5	—64.3	—83.7
500	....	3.9	39.0	13,000	....	—67.6	—89.7
1,000	....	1.7	35.1	14,000	...	—65.0	—85.0
1,500	....	—3.3	26.1	15,000	....	—64.8	—84.6
2,000	....	1.2	34.2	16,000	10.0	—64.1	—83.4
2,500	....	—0.2	31.6	17,000	....	—63.6	—82.5
3,000	....	—3.2	26.2	18,000	....	—62.9	—81.2
4,000	2.5	—8.7	16.3	19,000	...	—62.6	—80.7
5,000	....	—14.4	6.1	20,000	13.0	—62.6	—80.7
6,000	....	—21.4	—6.5	21,000	....	—62.3	—80.1
7,000	....	—28.3	—18.9	22,000	....	—62.1	—79.8
8,000	5.0	—36.2	—33.2	23,000	....	—61.8	—79.2
9,000	....	—44.3	—47.7	24,000	15.0	—62.3	—80.1
10,000	....	—52.0	—61.6	25,000	....	—62.5	—80.5
11,000	....	—58.4	—73.1	26,000	16.2	—62.7	—80.9

Thus a well-marked temperature inversion occurred at the height of 1,500 metres, and after a height of thirteen kilometres, or about eight miles, there was a decided rise of temperature for a considerable distance. During the last five miles of the ascent variations were but slight.

---

* *Ciel et Terre*, 1st January, 1909.

It may be pointed out that De Bort's discovery of the isothermal region had, in a way, been anticipated by MM. Hermite and Besançon. They, however, could not believe in the actual existence of a region of relatively warm air at a great height, such as was apparently indicated by their instruments, and considered that their observations became unreliable in the rare upper air, owing to the effect of the intense solar radiation there experienced.* But M. de Bort submitted to the Academy of Sciences of Paris in 1902 an exhaustive account of his researches, and expressed the confident opinion that the unexpected results of temperature observations at great heights represented a physical fact. He had indeed been satisfied of this some years earlier, but had carefully improved his methods, in particular devising means of regulating the speed of ascent of the balloons, so that the instruments should have time to accommodate themselves to the varying temperature conditions of successive heights. Moreover, his ascents at Trappes had been made at night, so as to avoid the direct effect of solar radiation. Taken along with experimental work by Professor Assmann in Germany, M. de Bort's researches placed the reality of the isothermal layer beyond doubt. Quite recently the matter has been thoroughly discussed in an interesting correspondence in the columns of *Nature* (vols. lxxvii.-lxxx.).

M. de Bort's work has been followed up in many countries. He himself, in 1907, organized an expedition to Kiruna, in Lapland, just within the Arctic Circle, and there, too, the isothermal layer was found to exist.† It had been found, too, many times in England; in several countries of the continent of Europe; in America, from St. Louis, by Mr. Rotch; by Professor Hergesell and the Prince of Monaco, in the neighborhood of the Azores; and on the cruises of the *Otaria,* as far south as 25° N. It had, however, not been found to the south of that parallel, though aerial soundings over the equatorial Atlantic had several times exceeded 15 kilometres.‡ M. de Bort, therefore, regarded the phenomenon as universal, except as regards the tropics. Now, however, even that restriction may be removed, for on the German expedition of last year Professor Berson found the upper temperature inversion on several occasions at great heights over tropical East Africa.§

**C.R.*, cxvi. 766. †*C.R.*, vols. cxlv. 149. ‡*Nature*, vol. lxxx. 219. §*Nature*, vol. lxxx. 171.

In one of his earliest communications, M. de Bort had pointed out that the height of the isothermal layer varies with variations of the sea-level pressure distribution, lying nearer to the ground than its average height over a low-pressure area, and farther from the ground above high-pressure areas. And what is true as regards a particular point, is true on a larger scale, for there appears to be a gradual increase in the average height of the layer as we pass from the lower pressure of the polar regions into the heart of the Atlantic anti-cyclone. In America, Rotch's investigations from St. Louis, in Lat. 35° N., showed that there the warm stratum is "at a decidedly higher altitude than it is in Northern Europe."*

Another remarkable discovery in connection with the higher atmosphere is the fact that at a height of five or six miles the day-to-day changes of temperature are more important than at the surface of the earth; variations of 30° F., or more, may occur with a low-level variation of but a few degrees. De Bort gives a striking example from the results of simultaneous ascents made from Paris and from Hald in Jutland. On 14th March, 1903, the temperature of the upper air over the two places at a height of about two and a half miles was the same,—about 3° F. On the following day, temperature at the same elevation over Paris had fallen about 2°; over Jutland, it had dropped to 36° below zero, a fall of about 40°; whilst the surface temperature at both places had varied but slightly. "Such facts show that we cannot theorize on atmospheric phenomena as if they were continuous in time and space; such cases, on the contrary, are rare, and limited to certain atmospheric conditions."

Lastly, it has now been demonstrated that the geographical distribution of temperature in the upper air is very different from that at the earth's surface. Surprisingly low temperatures were found at great heights over the North Atlantic, and Berson found over equatorial East Africa, at an elevation of about thirteen miles, a temperature of —119° F., "a lower temperature than ever registered at equal or even greater heights in Europe!" On the other hand, the upper-air temperatures above the Arctic Circle were found to be very high. We quote M. de Bort—

> ". . . In the lower layers the temperature of the equatorial zone exceeds that of the Arctic regions by 25° C. (45° F.). This excess of temperature decreases as the altitude increases until at a height of 10 or 11 kilometres it is as warm over the Arctic Circle as it is over the equatorial zone. With further increase in height there is no further decrease in temperature over the Arctic Circle, because

---

* *British Association Report*, 1908, p. 594.

the isothermal region is reached. But in the neighborhood of the Equator rapid decrease of temperature with increasing altitude still continues; the temperature becomes less therefore over the Equator than it is at the same height over the Arctic Circle. . . . There are indeed some days when the polar temperatures are lower than the equatorial, but this is a temporary phenomenon which occurs at the coldest time of the year. In equatorial regions, on the contrary, if one considers as the point of departure the region where the trade-winds meet near the thermal equator, there is, strictly speaking, neither winter nor summer. . . . Thus during the greater part of the year it is sensibly colder by 10° or 20° C. in the equatorial regions at altitudes of 15 or 16 kilometres than in Arctic regions. This fact, anticipated by me some years ago, deserves to be taken into serious consideration in theories relating to the general circulation."*

The explanation of the phenomenon of the "isothermal layer" involves physical problems of great difficulty, and we can merely refer to the work of Gold† in England and Humphreys in America.‡ The latter points out that the abruptness of the change of temperature gradient at the entrance to the region of relatively warm air is probably due to the existence at the critical level of a more or less well-defined veil of cirrus cloud, and shows that when the veil is fully formed the increase of temperature is rapid, whilst with a clear sky the reversal of gradient is more gradual. As regards Gold's researches we repeat from our last issue a summary of his remarks at the Dublin (1908) meeting of the British Association, which indicates the ground covered by the paper referred to below:

"Any theory of the isothermal layer must be primarily concerned with the absorption and emission of heat radiation by the atmosphere. The streams of radiation entering any layer were four—the solar radiation, the radiation from the atmosphere above the layer, the terrestrial radiation, and the radiation from the atmosphere below the layer. If the total amount of these four streams absorbed by the layer was less than the radiation emitted, its temperature must fall, and there would be the possibility of convective equilibrium. But if the absorption exceeded the emission, the temperature of the layer would rise, and there would be no possibility of convective currents penetrating from beneath. By utilizing the experimental results of Langley, Paschen, and others to obtain an estimate of the absorptive power of the atmosphere, he had calculated the intensity of radiation entering any layer and the amount absorbed there. The application of the results to our atmosphere led to the results that, if the air were divided into two layers, the lower in adiabatic, the upper in isothermal equilibrium, the upper layer must extend as low down as 10 kilometres, where the pressure was one-quarter of that at the earth's surface, and it could not extend below 4½ kilometres, where the pressure was one-half that of the earth's surface. A further result obtained was that it was impossible for there to be a temperature as low as —100°C. at any point of the atmosphere."

---

* *British Association Report*, 1908, p. 641.

† "The Isothermal Region of Atmosphere and Atmospheric Radiation." By E. Gold, M.A. *Proceedings* of the Royal Society, A. vol. lxxxii. pp. 43-70.

‡ "Vertical Temperature Gradients of the Atmosphere, especially in the Region of the Upper Inversion." By Prof. W. J. Humphreys. *Bulletin of the Mount Weather Observatory*, vol. ii. part 1.

Any student of the subject must also refer to theoretical researches made twenty years ago by M. de Bort, who calculated from the pressure and temperature at the earth's surface the isobars at a height of 4,000 metres (about 2½ miles). He showed that most of the areas of high and low pressure observed near the ground become quite effaced at higher levels, where there is a much less complex pressure distribution.*

---

* See *Annales du Bureau Central Météorologique*, 1887 and 1888.

September 1909.

Note.—Since the above paper was passed for press, there has been published a valuable report, communicated to the British Association (Winnipeg, 1909) by Messrs. E. Gold and W. A. Harwood, on "The Present State of our Knowledge of the Upper Atmosphere as obtained by the use of Kites, Balloons, and Pilot Balloons." The title of Advective Region is suggested for the so-called "Isothermal Layer," and M. de Bort has suggested Stratosphere as a suitable title. In contradistinction, that portion of the atmosphere below the "Isothermal Layer" would be known as the Convective Region, or Troposphere.

There will be presently published by the Meteorological Office a report on "The Free Atmosphere in the Region of the British Isles," in which Mr. Dines gives a full account of his instruments and methods, and Dr. Shaw discusses "The Perturbations of the Stratosphere."

November 1909.

THE HIGHEST BALLOON ASCENSION IN AMERICA

Dr. A. Lawrence Rotch has a short account in *Science* (No. 766) of the results of balloon experiments in our eastern states in 1908. His statement follows:

"Although a large number of *ballons-sondes* were despatched from St. Louis in 1904-7 under the direction of the writer, none had been employed in the eastern states until 1908. In May and July, that year, four *ballons-sondes* were launched from Pittsfield, Mass., with special precautions to limit the time they remained in the air and to prevent them from drifting out to sea with the upper westerly wind. Three of the registering instruments have been returned to the Blue Hill Observatory with good records. The first instrument sent up on May 7 was not found for ten months and the record,